APPENDIX B

Selected Marina Water Quality Studies from Around the World

Several studies worldwide document water quality conditions in marinas by analyzing marina sediment, water, and mussel tissue samples. This appendix summaries key marina studies worldwide. It does not summarize studies conducted in California, which are included in Chapter Two. Many of the studies described in this section were conducted in marinas that have different characteristics and conditions than California marinas.

Studies Documenting Metals in Marinas. Several studies worldwide document elevated metals concentrations in marinas. A 1991 study by the North Carolina Department of Environmental Management on North Carolina marinas found that copper and zinc were detected in oyster tissue samples at significantly higher concentrations within the marinas compared with reference stations outside the marinas. In addition, sediment samples showed significantly higher concentrations of copper, zinc, arsenic, cadmium, chromium, lead, mercury, and nickel within marinas compared with reference sites. While these sediment concentrations were elevated, they were not high enough to be considered toxic to marine life.**1**

In a study of South Carolina marinas, Marcus and Thompson (1986) found detectable concentrations of copper, zinc, cadmium, lead, nickel, and chromium in oyster tissue at the sampled marinas. While these concentrations were similar to South Carolina oysters in other non-marina areas, dynamic zinc and copper concentrations were found to be highly correlated with marina proximity.[2] Another study by Marcus and Swearingen (1988) found copper, zinc, lead, chromium, and nickel at elevated concentrations in sediment at an excavated boat basin in Murrells Inlet, South Carolina. Metals in this basin were significantly higher than other marinas in South Carolina, and this was found to be due to low water circulation.[3]

[1] NCDEM 1991. *Coastal Marinas: Field Survey of Contaminants and Literature Review*. Report #91-03. North Carolina Department of Environment, Health, and Natural Resources, Division of Environmental Management, Water Quality Section.
[2] Marcus, J.M., and A.M. Thompson. 1986. *Heavy Metals in Oyster Tissue Around Three Coastal Marinas*. Bulletin of Environmental Contamination and Toxicology 36: 587-594
[3] Marcus, J.M. and G.R. Swearingen, A.D. Williams, and D.D. Heizer. 1988. *Polynuclear aromatic Hydrocarbons and Heavy Metals Concentrations in Sediments at Coastal South Carolina Marinas.* Archives of Environmental Contamination and Toxicology 17: 103-113

In Chesapeake Bay, Hall et al (1988) examined dissolved copper concentrations in waters of four recreational marinas. Three of these marinas had high dissolved copper levels, and recreational boats housed in these marinas were considered the likely source.[4]

A study by the Australian Environment Council in 1989 found that copper levels in *Saccostrea commercialis*, oysters transplanted to marinas from a 'clean' area, increased by three orders of magnitude and lead increased by up to thirty-three orders of magnitude. Zinc levels increased by two orders of magnitude, but were half of what was found just outside the marinas, making it difficult to identify whether the contamination was coming from marina activities, or not.[5]

In the Caribbean, sediments of two marinas in St. Thomas were sampled for metals by researchers from the University of Puerto Rico. Total metals concentrations were highest in the Independent Boatyard (IBY), the marina with the highest level of active vessel maintenance activity, with the highest concentrations found adjacent to the dinghy dock and vessel haul-out station (Al 5.28□g/g, As 13.55□g/g, Cd 0.47□g/g, Cu 1535□g/g, Fe 3.42□g/g, Pb 178.50□g/g, Ag 0.14□g/g, Sn 33.4□g/g, Zn 441.5□g/g). Wash down and maintenance activities were cited as a probable source. At the Crown Bay Marina (CBM), the total highest metals concentrations were found nearest to a storm drain (As 9.27□g/g, Cu 70.85□g/g, Ni 11.05□g/g, Zn 92.60□g/g) indicating urban runoff as the likely source of contamination.[6]

Studies Documenting Petroleum Hydrocarbons in Marinas. Several studies have found high concentrations of petroleum hydrocarbons in marinas, particularly those characterized by poor flushing. In a North Carolina study, mononuclear aromatic hydrocarbons were detected at higher frequency in the waters of marinas that had fueling services than at reference sites, although concentrations were low and did not violate the State's standard. These hydrocarbons included benzene, toluene, xylene, and ethyl benzene, which are components of gasoline and used as degreasers, in cleaners, and as fuel additives, solvents and thinners. Additionally, PAHs were detected in sediments at six marinas with fuel docks, and one marina had levels exceeding toxicity thresholds.[7] In South Carolina, Marcus et al (1988) examined petroleum hydrocarbons in sediments of three marinas. They found that samples taken near or in marinas yielded high PAH levels, and PAH levels increased in the larger marinas.[8] Elevated PAHs were also found in

[4] Hall, W., S. Bushong, L. Hall, M. Lenkevich, and A. Pinkney. 1988. *Monitoring Dissolved Copper Concentrations in Chesapeake Bay.* Environmental Monitoring and Assessment 11:33-42.
[5] McMahon, P.J.T. 1989. *The Impact of Marinas on Water Quality.* Water, Science, and Technology. Vol. 21, No. 2, pp 39-43, 1989.
[6] Hinkey, Lynne Marie 2001. "A Baseline Assessment of Environmental Conditions and the potential for Polycyclic Aromatic Hydrocarbons (PAHs) Biodegredation in Marina Waters and Sediments." A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Marine Sciences (Chemical Oceanography) University of Puerto Rico. Mayaguez Campus.
[7] NCDEM 1991
[8] Marcus et al 1988

an excavated boat basin in Murrels Inlet, South Carolina[9], and Wendt et al (1990) found PAHs in sediments in another South Carolina marina over three seasons, while none were found in the control site. The same study found PAHs in oysters collected from the marina during summer months, at levels well above the control site.[10] Yet another South Carolina study examined PAHs in oyster tissue at three coastal marinas. Oyster tissues collected from the two larger marinas in this study, contained a larger variety of PAH compounds than the smallest marina.[11]

A study of Chesapeake Bay marinas, which compared creeks containing marinas to creeks without marinas (and hence, less boating activity), found significantly higher levels of hydrocarbons (both aliphatic and aromatic) in the creeks containing marinas.[12]

In Washington State, the Washington State Department of Ecology studied sediment particulate matter and bottom sediments at two marinas in Thea Foss Waterway in Commencement Bay. PAHs were measured at levels above Commencement Bay sediment quality standards. However, there was no clear evidence isolating marina-related sources from other sources of this contamination. The marinas were not enclosed by breakwaters, allowing sediments and particulates to flow freely in and out.[13] In another study of four marinas in the San Juan Islands of Washington, total PAH concentrations in sediments were elevated, but did not exceed sediment quality standards.[14]

In the Caribbean, water and sediment of two marinas (Crown Bay Marina [CBM] and Independent Boatyard [IBY]) in St. Thomas were sampled for Polycyclic Aromatic Hydrocarbons (PAHs) by researchers from the University of Puerto Rico. This study illustrates the complexities with identifying the sources of contaminants in marinas. Elevated concentrations of PAHs in water and sediment at various stations around the two marinas were found, but researchers suggest that the concentrations within the marinas were similar to PAH inputs from non-marina activities such as urban runoff and wastewater treatment plant discharges. Average sediment PAH concentrations within both marinas was 384.6 ng/g, and the average outside the marinas was 125.5 ng/g. The highest concentrations of PAHs in water were found at the fuel dock of Crown Bay Marina (CBM) (1123.5 ng/L), however, in sediments near the same fuel dock, the lowest PAH concentrations were found (3.9 ng/g). Flushing patterns at CBM indicated, however, that petroleum from the fuel dock could have migrated through the water col-

[9] Marcus, J.M. and G.R. Swearingen. 1983. A Water Quality Assessment of Selected Coastal Marinas, Beaufort County, South Carolina. South Carolina Department of Health and Environmental Control. Technical Report No. 022-83.
[10] Wendt, P.H., R.F. Van Dolah, M.Y. Bobo and J.J. Manzi. *Effects of Marina Proximity on Certain Aspects of the Biology of Oysters and Other Benthic Macrofauna in a South Carolina Estuary.* South Carolina Marine Resources Center. South Carolina Wildlife and Marine Resources Department. Technical Report #74.
[11] Marcus, James M. and Tina P. Stokes. 1985 *Polynuclear Aromatic Hydrocarbons in Oyster Tissue Around Three coastal Marinas.* Bulletin of Environmental Contamination and Toxicology. 35:835-844
[12] Voudrias, E.A., and C.L. Smith. 1986. *Hydrocarbon Pollution from Marinas in Estuarine Sediments.* Estuarine, Coastal, and Shelf Science 22: 271-284.
[13] Washington State Department of Ecology (b). 2001. Contaminants Associated with Settling Particulate Mater and Bottom Sediments at Two Marinas in Thea Foss Waterway. Publication No. 01-03-023. Olympia, WA.

umn and deposited in sediments at the dinghy dock (which had a PAH concentration of 1102.9 ng/g in sediments) and the sampling station located in the low flushing area of the marina (which had a PAH concentration of 82.1 ng/g in sediments). A similar pattern was observed at Independent Boatyard Marina (IBY), where dinghy dock (408.6 ng/g) and low flushing stations (372.2 ng/g) had high PAHs in sediments, and these were located downwind and down current from a fuel dock in an adjacent marina. Dinghy engine exhaust were sited by researchers as also a likely source of PAHs at the dinghy docks of both marinas. At the Crown Bay Marina (CBM), however, in addition to vessel and fuel dock operations, another likely source was spills from oil tanks located across the road and entering the marina through a storm drain, and road run-off.[15]

Studies Documenting Bacterial Contamination in Marinas. A few studies have looked at the association of bacterial contamination and recreational vessels in marine waters but drawing conclusions is complicated by environmental and climatic conditions, flushing and water circulation patterns, and types of boats and usage at different marinas. Seabloom (1969) studied the water quality of Wallochet and Meydenbauer Bays in Washington State. It was found that vessel discharges adversely affected the bacteriological quality of Wollochet Bay, however, sampling results did not show an adverse affect in Meydenbauer Bay. Coliform levels could have been affected by exposure to sunlight, competition for nutrients, seawater temperature, and the existence of marine predators during the summer months.16 Fisher et al (1987) compared two marinas in North Carolina during a peak use period. They found elevated fecal coliform levels near boats during high periods of usage and occupancy, however, conditions were worse at the enclosed, lower flushing marina, compared to the open water marina. Differences in physical and hydrographic conditions, and difference in boat types and usage patterns were complicating factors in determining the contribution of boats to fecal coliform levels. This study does show that an open water marina, which allows for better water circulation and flushing, can substantially dilute and kill-off microbial contaminants from fecal waste discharges.17

In the Caribbean, researchers from the University of Puerto Rico examined fecal coliform levels in five marinas over three seasons (winter, spring, summer) in one year in Puerto Rico and the U.S. and British Virgin Islands. Approximately four stations (fuel dock, dinghy dock, low flushing area, outside marina) in each marina were sampled for at least two mornings and two afternoons in each season. While the sample size was small and insufficient to provide sta-

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[14]Washington State Department of Ecology (a). 2001. Concentrations of Selected Chemicals in Sediments from Harbors in the San Juan Islands. Publication No. 01-03-007.
[15] Hinkey 2001
[16] Seabloom, Robert W. 1969. *Bacteriological Effects of Small Boat Wastes on Small Harbors.* University of Washington College of Engineering. Seattle, Washington. July 1969.
[17] Fisher, John S., Richard R. Perdue, Margery F. Overton, Mark D. Sobsey and Ben L. Sill. 1987. *A Comparison of Water Quality at Two Recreational Marinas during a Peak Use Period.* UNC Sea Grant College Program. North Carolina State University. UNC Seagrant Publication #UNC-WP-87-1

tistically meaningful comparisons, results provided information on the need for research on the correlations between elevated fecal coliform levels at a fuel dock in summer and the presence of petroleum hydrocarbons (PAHs). Overall, the annual fecal coliform averages in the outside marina stations (57.6 cfu/500ml) were higher than within marina stations (50.1 cfu/500 ml). Both averages were higher than the control annual average of 11.1 cfu/500ml.[18]

Studies Documenting Nutrients in Marinas. In the Caribbean, researchers from the University of Puerto Rico monitored nutrients for one year, including the fall, winter, spring and summer, in five marinas in Puerto Rico and the U.S. and British Virgin Islands. Within the marinas, average nitrate and phosphate concentrations were higher than the average in control stations in every season except winter. Nitrate concentrations ranged from 0.0 □M to 3.5 □M (highest concentration at a station just outside of a marina). Phosphate concentrations ranged from 0.0 □M to 0.4 □M at a fuel dock station. Researchers speculated that fuel dock activities, such as using detergents to clean up boat bilges, as a likely cause.19 See Chapter Two for nutrient monitoring conducted in Lake Tahoe, California.

[18] Hinkey 2001
[19] Hinkey 2001